Graphical Analysis of B-737 Airplane Pathloss Data for GPS and Evaluation of Coupling Mitigation Techniques

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***Abstract*— The use of Portable Electronic Devices (PEDs) onboard commercial airliners is considered to be desirable for many passengers, However, the possibility of Electromagnetic Interference (EMI) caused by these devices may affect flight safety. PEDs may act as transmitters, both intentional and unintentional, and their signals may be detected by the various navigation and communication radios onboard the aircraft. Interference Pathloss (IPL) is defined as the measurement of the radiated field coupling between passenger cabin locations and aircraft communication and navigation receivers, via their antennas.**

This paper first focuses on IPL measurements for GPS, taken on an out-of-service United Airlines B-737-200. IPL pattern symmetry is verified by analyzing data obtained on the windows of the Port as well as the Starboard side of the aircraft. Further graphical analysis is performed with the door and exit seams sealed with conductive tape in order to better understand the effects of shielding on IPL patterns. Shielding effects are analyzed from window data for VHF and LOC systems. In addition the shielding benefit of applying electrically conductive film to aircraft windows is evaluated for GPS and TCAS systems.

Keywords-IPL, EMI, aircraft, shielding, GPS

I. Introduction

Previous work [1] includes background details on IPL measurements and testing methodology. Systems studied previously include the instrument landing system Glideslope (GS), Traffic Alert and Collision Avoidance System (TCAS), VHF Communication System #1 (VHF1), instrument landing system Localizer (LOC) and VHF Omniranging (VOR). Graphical analysis of full airplane measurements on the above systems provided valuable insight on the understanding of IPL pattern based on the aircraft size, antenna locations as well as the locations of doors and windows.

This paper adds analysis for a fifth aircraft radio system of concern: Global Positioning System (GPS), which operates at 1575.42 MHz [2]. As seen in Figure 1, the GPS antenna in a B737-200 is located behind the TCAS antenna (approximately above window location #9). The GPS antenna is not installed along the top centerline of the aircraft, but instead, is slightly offset to the Starboard side of the airplane. (See Figure 1). This location factor makes the analysis of IPL symmetry on the left and right (port and starboard) side of the aircraft very important. The next two sections include results from GPS analysis, as well as graphical analysis of mitigation techniques, which consisted on sealing the door and exit seams as well as taping of windows 1 through 12.

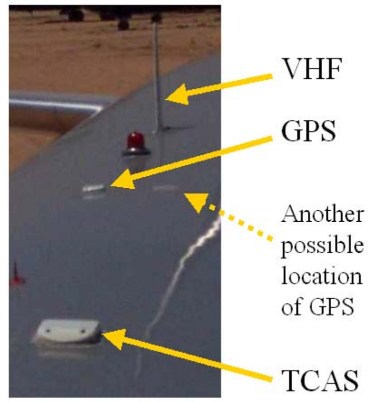

Figure 1. Antenna Locations on B737-200

II. PED EMI Mitigation By Conductive Sealing of Door and Exit Seams

In May of 2002, researchers from NASA Langley Research Center, United and Eagles Wings Inc. took a set of IPL measurements on the window locations using the GPS system. Below (Figure 2) is an interior schematic for B737-200. The

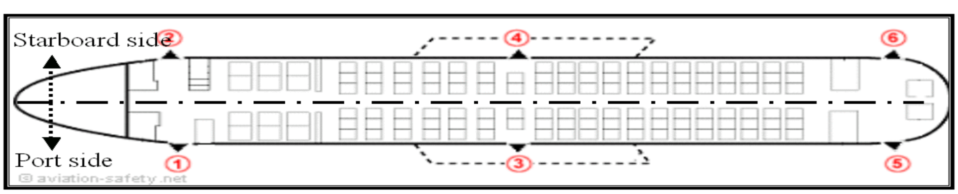

Figure 2. Schematic of B737-200, Port vs. Starboard side

Figure 3. Shielding of Door and Exit Seams on B737-200

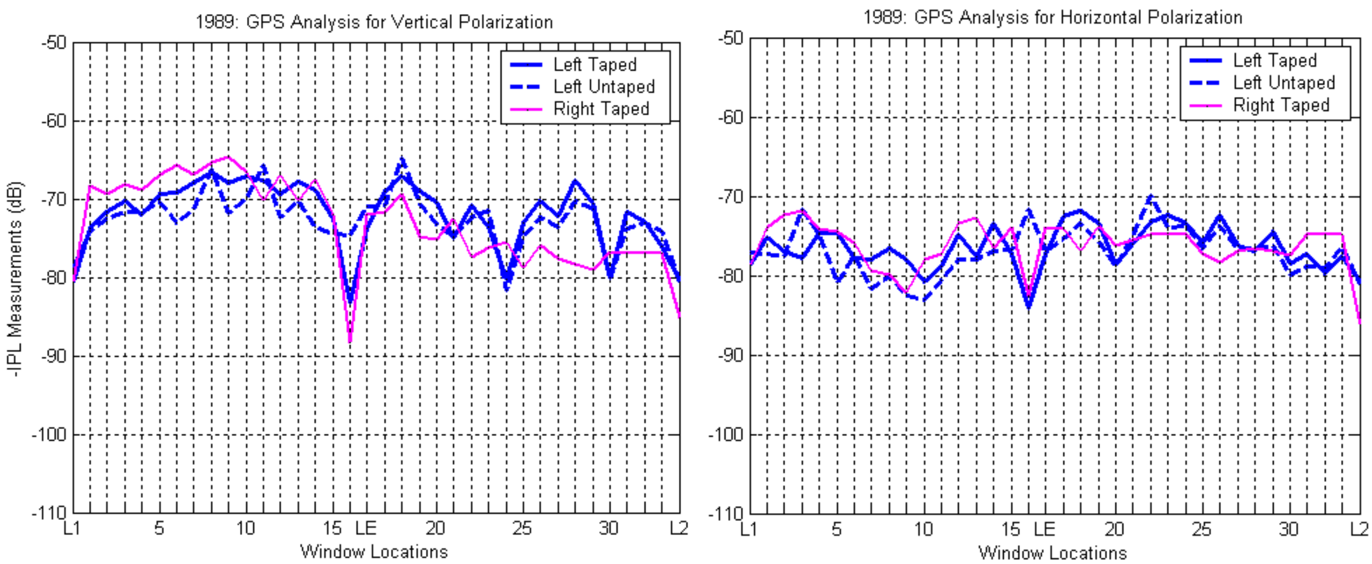

Figure 4. Coupling Level from Passenger Cabin to GPS Antenna on B737-200 (#1989)

schematic points out the port vs. the starboard side of the aircraft as well as the door locations as a reference for the analysis performed in the rest of this paper.

"Aircraft taping" required conductive sealing of all door and exit seams on both sides of the aircraft using heavy-duty aluminum foil and adhesive-backed aluminum tape (as shown in Figure 3).

A. Analysis of Shielding of exit seams on GPS

Figure 4, includes the plotted IPL data, in both horizontal and vertical polarizations, obtained on the window locations of the port (left) as well as starboard (right) sides of the aircraft (B-737#1989). The x-axis represents the window locations of the aircraft (window #1 being closest to the nose of the aircraft and #33 representing the window closest to the tail of the aircraft), while the y-axis represents calibrated IPL data, measured in dB. Notice in the legend that a dashed (blue,bold) line is used to represent the untaped data, while a solid (blue, bold) line is used to represent the taped data. Another solid (magenta, thin) line is used to represent the taped data on starboard side. Figure 4 shows that improved coupling (less loss) occurs for vertical polarization of the test antenna, rather than horizontal polarization.

Aircraft symmetry was tested by comparing the results obtained on the starboard, vs. port side of the aircraft in both polarizations. As shown in Figure 1, the GPS system has two possible locations for antenna installation on the United Airlines B-737-200 aircraft. In the case of B737-200 #1989, the GPS was installed in the starboard side of the airplane. This factor resulted in the assumption that the coupling on the starboard side should be slightly higher than the coupling on the port side. By observing the solid magenta and blue lines in Figure 4, it can be seen that the starboard side, indeed, had a greater IPL measurement from windows #1 to #9; however, the measurements deviated between high and low between port and starboard side after window #10, when moving toward the tail of the aircraft.

Some IPL measurements were obtained by moving the test antenna along the entire circumference of a door or window exit seams, while measuring the maximum coupling over the entire sweep. These are defined as "door sweep" measurements. The tick-marks on the x-axis, labeled 'L1', 'LE' and 'L2', represent the "door sweeps" performed on window locations 1, 16 and 33 respectively. Door sweep was measured to understand the effects on IPL measurements due to leakage from the door seams (versus the windows).

The effects of taping the door and exit seams were analyzed by comparing the solid and dashed blue lines in Figure 4. As seen in the figure, there is not much difference between the untaped and taped results on the port side throughout the aircraft windows, except at window #16. Since window #16 is located on the exit, where the window and door seam was sealed, there is a measurement drop of about 8 dB between the taped and untaped results (taped, having the lower IPL measurement). It was observed that although much difference was observed between the taped and untapped IPL measurement *at* the sealed window location (#16), there was not much difference in the IPL measurement taken at the door sweep. For instance, the measurements at ‘LE’ are very close to the measurements taken at window #15 and window #17; however, the IPL result *at* window #16 is noticeably lesser than the surrounding windows #15 and #17. This shows that sealing aircraft’s exit window was indeed helpful for GPS, but not the door seam.

B. *Analysis of Shielding of Exit Seams on VHF1*

The VHF1 system antenna is located on top of window #16 of the aircraft. (Most commercial transport airplanes have three VHF Com systems with separate antennas mounted on the fuselage.) Although detailed analysis of the overall IPL pattern is presented in [1], the specific effects of conductive sealing of door and exit seams are shown in Figure 5. For this analysis, IPL measurements were taken at the window locations of the port side in both horizontal and vertical polarizations, both with and without taping. For the VHF system, the vertical polarization is dominant. As observed in the left plot of Figure 5, coupling from all passenger cabin window locations was reduced by about 5 dB, and even greater drop of up to 15 dB was observed at the door and window exit locations, where the seams were conductively sealed.

C. *Analysis of Shieldingof Exit Seams on LOC*

The VOR/LOC System antennas are located on the tip of the tail of the aircraft. Please refer to [1] for further details on IPL analysis and results derived from data taken on the entire aircraft. Figure 6 shows the effect of unshielded versus conductive sealing of door and exit seams on IPL window data taken on the port side of the aircraft in both vertical and horizontal polarizations.

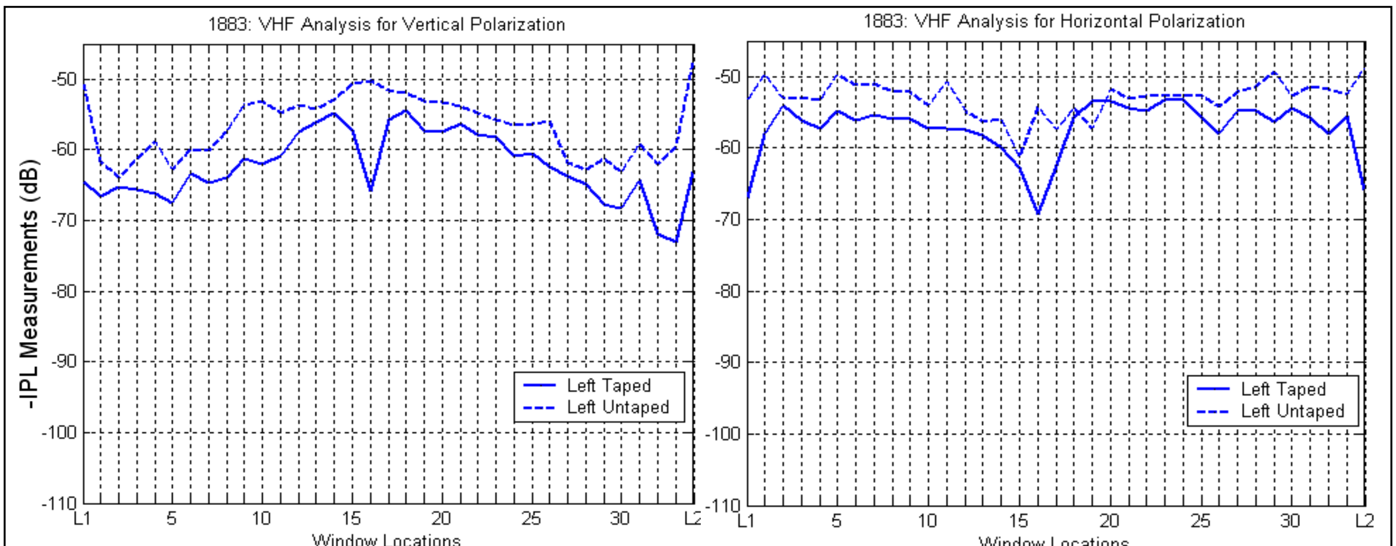

Figure 5. Coupling Level from Passenger Cabin to VHF1 Antenna on B737-200 (#1883)

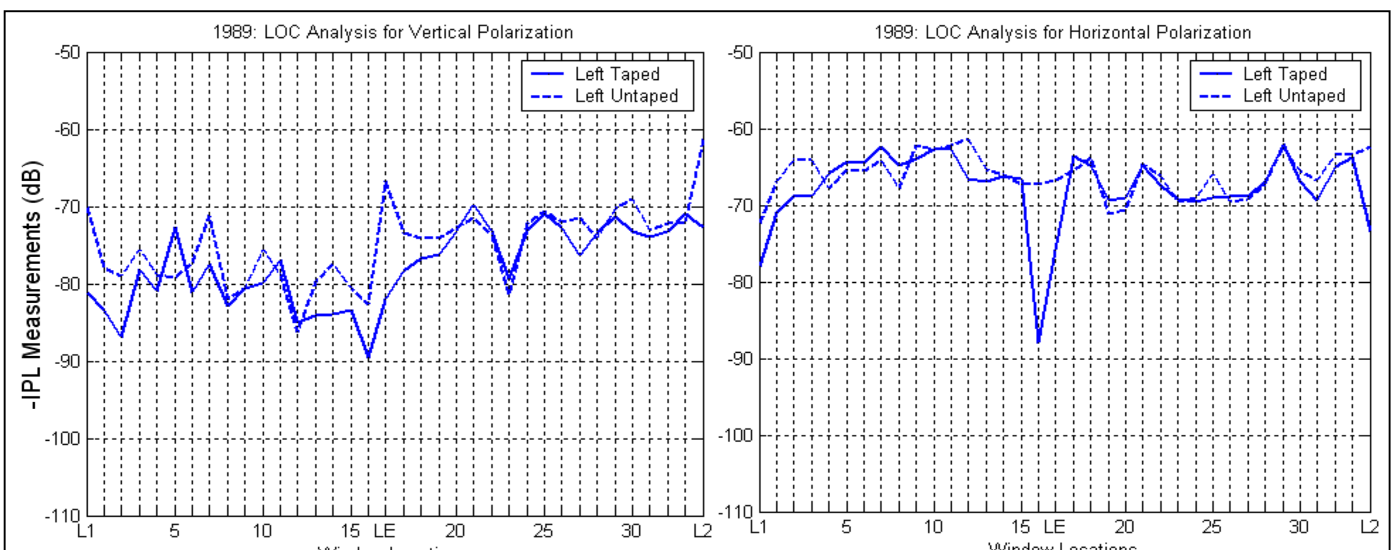

Figure 6. Coupling Level from Passenger Cabin to LOC Antenna on B737-200 (#1989)

The horizontal polarization is dominant for the Localizer system. There is not much difference between the IPL readings for taped and untaped results throughout the aircraft, except at window 16. For the LOC system (horizontal), the IPL measurement dropped about –20 dB at window 16 after the exit seams and window 16 were taped. In vertical polarization results, more than 12 dB of coupling reduction was obtained at the L1 and L2 doorways when the seams were conductively sealed.

III. PED EMI Mitigation By Conductive Window Films

Figure 7 shows another kind of shielding technique used for IPL measurements by taping electrically conductive window films from windows #1 to #12 on the starboard (right) side of B737-200 (#1879). The particular film used was Cortaulds VS-60 "spectrally selective" film, having a high visible light transmittance (58%), and high silver content. The film sample was obtained from the manufacturer (CPFilms), in 1998. No surface resistance data was available for the VS-60 film at the time of this analysis, but since 1998, new films with higher visible light transmittance have been introduced specifically for EMI shielding applications. [5] In this case, the film was temporarily bonded to the aircraft using 2"-wide aluminum tape. IPL measurements were performed with and without the film installed.

A. Analysis of Window Films on GPS

As shown in Figure 1, the GPS is located above window #9 on B737-200. Figure 8 shows the IPL measurements obtained with and without window film installed. As described in the legend, dashed line is used to represent "unfilmed" data, while a solid line is used to represent data with window films on windows #1 through #12. As seen in both graphs for horizontal and vertical polarization, the IPL measurements after window #12 are very close to each other for both filmed and unfilmed aircraft. However, there is an average of about –13 dB drop in IPL results on windows #1 through #12, where the window film was applied. This analysis shows that conductive window films may be very effective in reducing coupling from the passenger cabin to aircraft GPS antennas.

B. Analysis of Window Films on TCAS

The upper TCAS antenna is located above window #2 on B737-200. Additional IPL measurements were obtained with the film applied from window #1 through #12 (as shown in Figure 7). Measurements were taken in both horizontal and vertical polarizations from windows #1 through #16, with and without, window films. Figure 9 shows the results in both vertical and horizontal polarization. For TCAS, the vertical polarization is dominant.

Figure 7. Window Films on B737 (Starboard). (W1 -> W12)

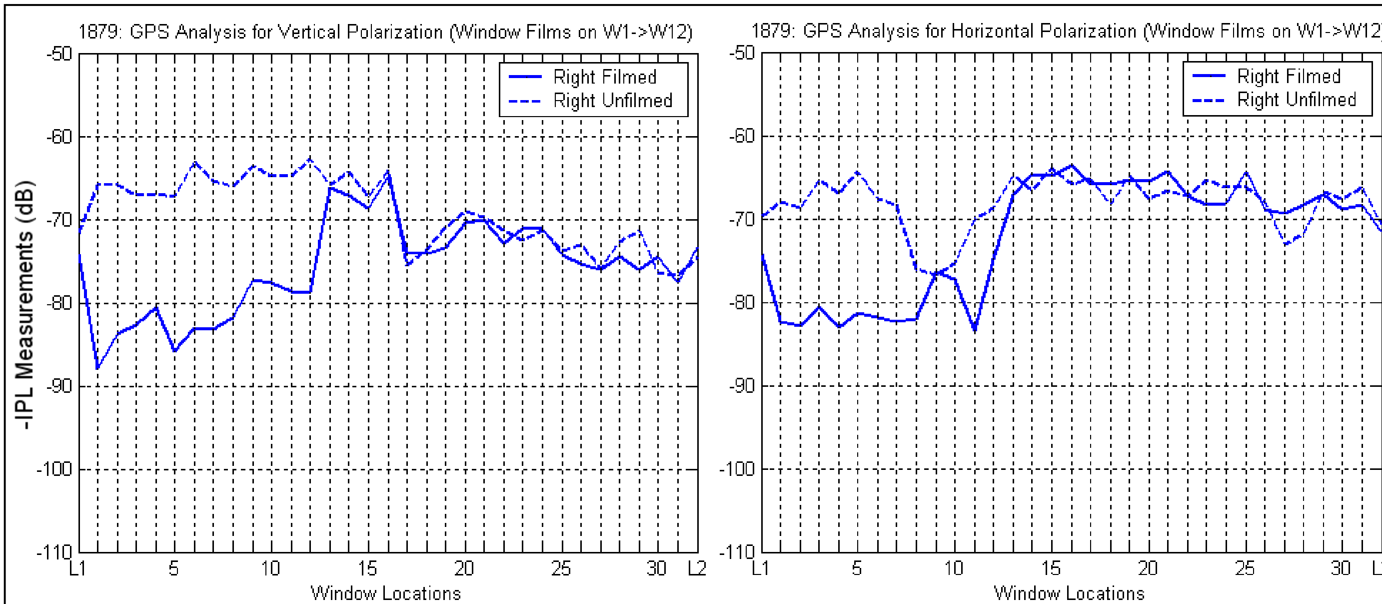

Figure 8. GPS Analysis of Window Films on B737-200 (#1879)

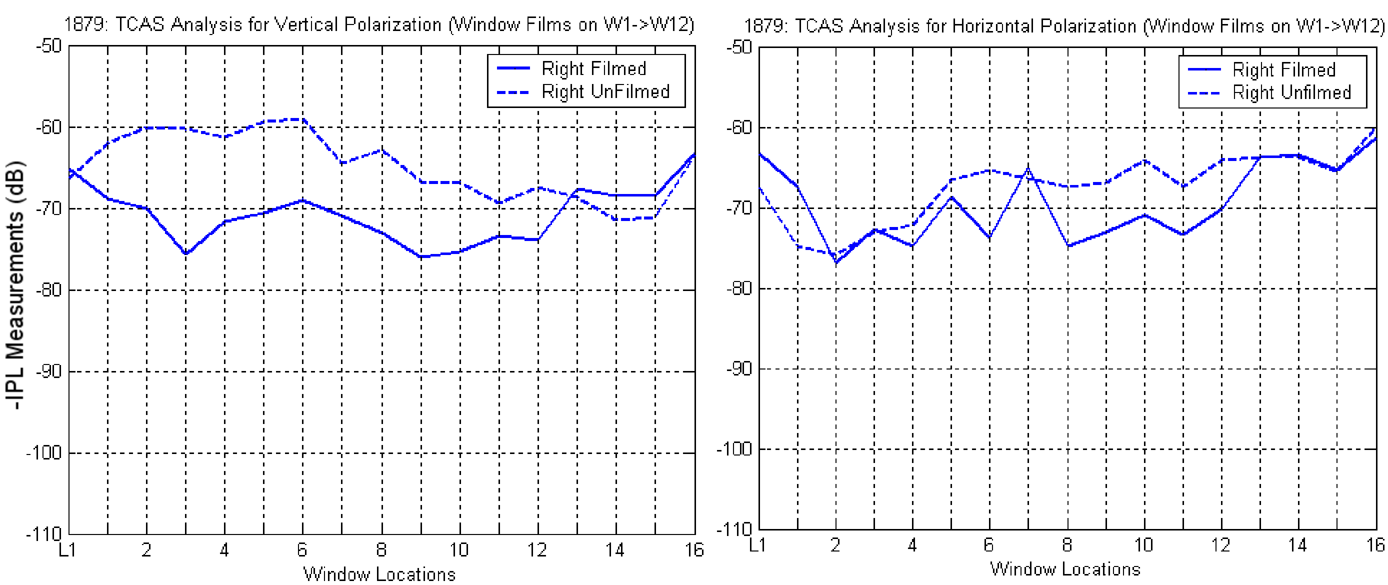

Figure 9. TCAS Analysis of Window Films on B737-200 (#1879)

As seen in figure 9, vertical polarization, there is about a -10 dB drop between filmed and unfilmed window coupling. The difference between the dashed and solid line actually decreases, as approaching window #12 (last taped window), and finally, the coupling levels are almost equal after windows #12. In horizontal polarization, there is not much difference between the filmed and unfilmed windows' IPL measurements. Similar to the GPS result, the use of conductive window films is shown as an effective method of reducing coupling levels from the passenger cabin to TCAS as well.

IV. Conclusion

This paper provides analysis of previously unpublished IPL data measured on out-of-service United Airlines B737-200 aircraft. IPL measurements taken on the port vs. starboard side of the aircraft clearly show that the GPS antenna installation being offset toward the starboard side of this particular airplane results in about 5dB higher coupling from the starboard side.

The merit of PED EMI mitigation by conductive sealing of door and exit seams was evaluated by measuring airplane IPL with (and without) aluminum foil bonded along all window and door exit seams along both sides of the airplane. IPL measurement comparisons were performed for the VHF1 communications, LOC and GPS aeronautical radio systems. Coupling from all passenger cabin window locations to the VHF1 aeronautical communication system was reduced by about 5dB, and an even greater benefit, up to 15dB, was obtained at the door and window exit locations when the seams were conductively sealed. For LOC, coupling at most window locations was not significantly reduced. More than 10 dB of coupling reduction was obtained at the doorways when the seams were conductively sealed.

Coupling at window and door seams usually sets the minimum IPL used in previous PED EMI assessments to airplanes. For GPS, virtually no coupling reduction was obtained by conductive sealing anywhere except directly at the window covered by aluminum foil. These results demonstrate an upper bound to the degree of PED EMI mitigation that may be obtained by improving the electrical bond between door and exit seams on commercial transport airplanes. It is expected that these results are representative of the level of protection that would be afforded to other aircraft radio systems operating in the VHF and "L" (1 to 2 GHz) radio frequency bands, and having similar antenna locations.

The merit of PED EMI mitigation by the application of conductive window film was evaluated by measuring airplane IPL with (and without) film installed on the first 12 windows on the starboard side of the airplane. It was shown that coupling levels may be reduced by more than 15 dB for GPS and more than 10 dB for TCAS by application of conductive window film. These results demonstrate that the application of conductive films to aircraft windows may provide significant reduction in PED EMI coupling to aircraft radio systems. This testing did not evaluate the level of protection possible to aeronautical radio systems operating in the VHF and UHF radio frequency bands (ie. VHF Com, VHF Omniranging, LOC, Glideslope) by applying conductive window film.

It is recommended that more comprehensive evaluations of conductive sealing of door seams combined with conductive window films be performed for all aircraft radio systems in the future. These tests should consider aging issues and maintenance strategies in the selection of materials and their installation.

ACKNOWLEDGMENTS

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